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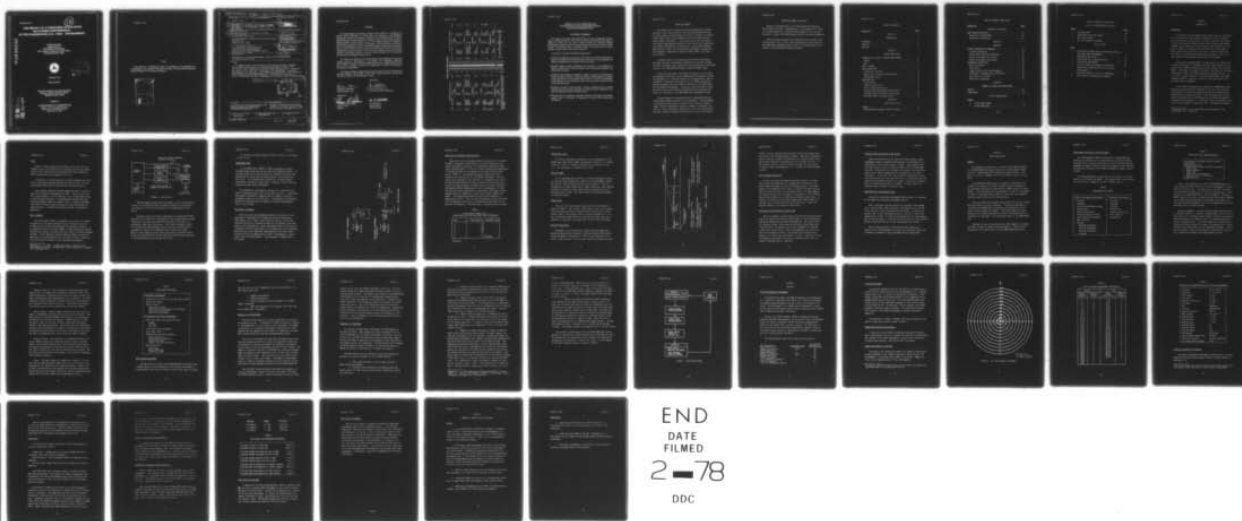
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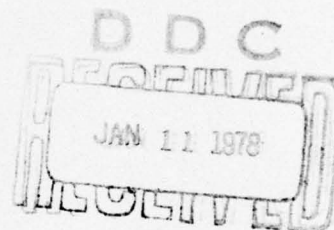
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**THE IMPACT OF A PROPOSED ACTIVE BCAS  
ON ATCRBS PERFORMANCE  
IN THE WASHINGTON, D.C., 1981 ENVIRONMENT**

AD A048589

IIT Research Institute  
Under Contract to  
DEPARTMENT OF DEFENSE  
Electromagnetic Compatibility Analysis Center  
Annapolis, Maryland 21402



September 1977

FINAL REPORT

Document is available to the public through the  
National Technical Information Service,  
Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
Systems Research & Development Service  
Washington, DC 20590

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(19) PR-77-037, 77/240

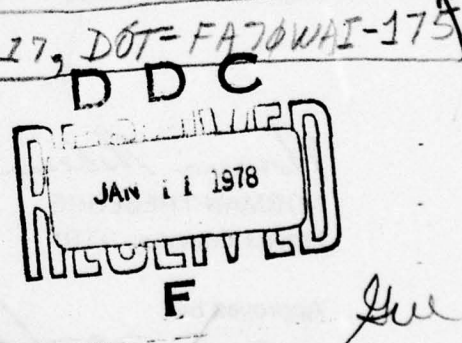
TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-RD-77-140 ✓	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE IMPACT OF A PROPOSED ACTIVE BCAS ON ATCRBS PERFORMANCE IN THE WASHINGTON, D.C., 1981 ENVIRONMENT.	5. Report Date Sep 1977	6. Performing Organization Code
7. Author(s) Norman Theberge of IIT Research Institute	8. Performing Organization Report No. ECAC-PR-77-037	9. Performing Organization Name and Address DoD Electromagnetic Compatibility Analysis Center North Severn Annapolis, MD 21402
10. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	11. Work Unit No. 10/48p.1	12. Contract or Grant No. DOT-FA70WAI-175 Task 32-A-1
13. Supplementary Notes Performed for the Spectrum Management Staff, Systems Research and Development Service, FAA.	14. Type of Report and Period Covered FINAL rept,	15. Sponsoring Agency Code 66495
16. Abstract A computer model of the proposed active Beacon Collision Avoidance System (BCAS) was developed to investigate the impact of BCAS on the Air Traffic Control Radar Beacon System (ATCRBS) ground system. Predictions were made for the early 1981 Washington, D.C., environment. Two ground environments were simulated, an all-ATCRBS environment and a 25%/75% Discrete Address Beacon System (DABS)/ATCRBS mix. Airborne fruit rates and the effect of BCAS/DABS mode power programming on interference were also predicted.		
17. Key Words AIR TRAFFIC CONTROL RADAR BEACON SYSTEM (ATCRBS) BEACON COLLISION AVOIDANCE SYSTEM (BCAS) DISCRETE ADDRESS BEACON SYSTEM (DABS) ELECTROMAGNETIC COMPATIBILITY		
18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161		
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 48
22. Price		

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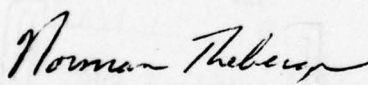
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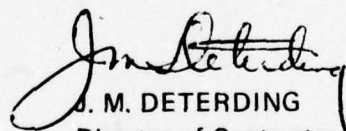
The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-76-C-0017, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

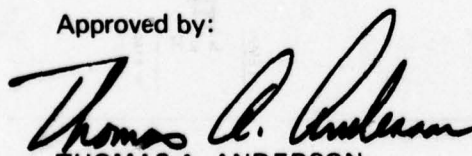
To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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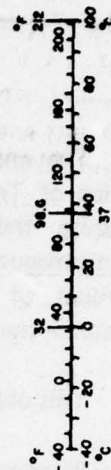
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# METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
<b>LENGTH</b>				<b>LENGTH</b>			
in	inches	*2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	1.1	yards
<b>AREA</b>				<b>AREA</b>			
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>	square centimeters	0.16	square inches
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>	square meters	1.2	square yards
yd <sup>2</sup>	square yards	0.8	square meters	km <sup>2</sup>	square kilometers	0.4	square miles
mi <sup>2</sup>	square miles	2.6	square kilometers	ha	hectares (10,000 m <sup>2</sup> )	2.5	acres
<b>MASS (weight)</b>				<b>MASS (weight)</b>			
oz	ounces	28	grams	g	grams	0.035	ounces
lb	pounds	0.45	kilograms	kg	kilograms	2.2	pounds
	short tons (2000 lb)	0.9	tonnes	t	tonnes (1000 kg)	1.1	short tons
<b>VOLUME</b>				<b>VOLUME</b>			
tsp	teaspoons	5	milliliters	ml	milliliters	0.03	fluid ounces
Tbsp	tablespoons	15	milliliters	l	liters	2.1	pints
fl oz	fluid ounces	30	milliliters	m <sup>3</sup>	cubic meters	1.06	quarts
c	cups	0.24	liters	m <sup>3</sup>	cubic meters	0.26	gallons
pt	pints	0.47	liters	m <sup>3</sup>	cubic meters	35	cubic feet
qt	quarts	0.95	liters	m <sup>3</sup>	cubic meters	1.3	cubic yards
gal	gallons	3.8	liters				
ft <sup>3</sup>	cubic feet	0.03	cubic meters				
yd <sup>3</sup>	cubic yards	0.76	cubic meters				
<b>TEMPERATURE (exact)</b>				<b>TEMPERATURE (exact)</b>			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



\*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 230, Units of Weights and Measures, Price \$2.25, SO Catalog No. C13.10-286.

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SYSTEMS RESEARCH AND DEVELOPMENT SERVICE  
SPECTRUM MANAGEMENT STAFF**

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The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

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- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

## EXECUTIVE SUMMARY

The proposed active Beacon Collision Avoidance System (BCAS) analyzed in this report provides the collision-avoidance function for BCAS-equipped aircraft against aircraft with either Air Traffic Control Radar Beacon System (ATCRBS) or Discrete Address Beacon System (DABS) transponders. This system actively elicits replies from other beacon-equipped aircraft in the vicinity by transmitting both ATCRBS- and DABS-type interrogations. The Federal Aviation Administration (FAA), the system proposal developer, requested the Electromagnetic Compatibility Analysis Center (ECAC) to perform this analysis.

A computer model of the proposed active BCAS was developed. The model simulates interrogations generated by aircraft equipped with BCAS and merges these signals with those generated by the ground system in the DABS/ATCRBS Performance Prediction Model (PPM).

Predictions were made to determine the impact of active BCAS electromagnetic emissions on the ATCRBS ground interrogator located at Washington, D.C., National Airport for the hypothetical 1981 environment. Predictions were made for an all-ATCRBS interrogator ground environment and for a mixed environment of 25% DABS sensors and 75% ATCRBS interrogators. Predictions were also made to determine fruit rates at an airborne interrogator and to evaluate the effects of variations in the BCAS/DABS power programming scheme.

The performance of the ground system is determined with and without BCAS-equipped aircraft in the environment. The performance is determined statistically in terms of reply hit-miss histories, target detection and mode A (identity) and mode C (altitude) validation. Other interference conditions, such as individual garbles and reply blanking by DABS roll-call fruit, are also investigated.

EXECUTIVE SUMMARY (Continued)

Based on the predictions, it was determined that deploying active BCAS in the 1981 Washington, D.C., environment will result in a slight reduction in aircraft reply probability, but not sufficiently to impact the ATCRBS ground receiver/processor performance.

Other predictions showed that instantaneous fruit rates at an airborne BCAS of up to 7200/s could be expected at 20,000 feet and that DABS power programming had no effect on BCAS-generated interference in the Washington ATCRBS environment.

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## SECTION 1

## INTRODUCTION

BACKGROUND

The Federal Aviation Administration (FAA), which is responsible for aviation safety, was directed by Congress to find a reliable Collision Avoidance System (CAS). Several systems that are compatible with the existing FAA Air Traffic Control Radar Beacon System (ATCRBS) signal formats have been proposed. These systems are generally referred to as Beacon Collision Avoidance Systems (BCAS). These systems are either active or passive. Passive systems monitor replies elicited by ground-based interrogations. Active systems transmit interrogations from airborne interrogators.

One currently proposed BCAS,<sup>1</sup> as analyzed in this report, has a signal format which is compatible with the signal formats of both the existing ATCRBS and the proposed Discrete Address Beacon System (DABS). This BCAS is intended to provide the CAS function in a mixed environment of DABS- and ATCRBS-transponder-equipped aircraft. It is an active system capable of interrogating both DABS- and ATCRBS-equipped aircraft as opposed to passive systems that monitor the existing signal environment.

Active BCAS interrogations may degrade the ATCRBS/DABS ground system by causing additional transponder dead time, thus lowering the probability of reply and impacting processor performance when combined with increased fruit rates. The FAA tasked ECAC to investigate the impact of active BCAS operation on ATCRBS performance in a hypothetical Washington, D.C., area early 1980's environment (based on the 1975 environment increased by 20%). Two ground environments,

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<sup>1</sup>Preliminary Draft, Active BCAS Engineering Requirement, FAA, Washington, D.C., 1 June 1976.

one consisting of only ATCRBS interrogators and the other a 25%/75% mix of DABS sensors/ATCRBS interrogators, were considered.

#### OBJECTIVE

The objective of the analysis was to determine the electromagnetic impact of active BCAS on ATCRBS in the postulated Washington, D.C., early 1980's environment.

#### APPROACH

Using the time-event-store DABS/ATCRBS Performance Prediction Model (PPM), appended with a submodel of the active BCAS, an analysis was conducted to determine the impact of active BCAS electromagnetic emissions on the performance of the ATCRBS ground system.

The performance of the ATCRBS was predicted with and without the active BCAS in the Washington, D.C., common ATC environment, which was generated from Suitland enroute site radar target printouts supplemented with FAA forecasts for future air environments. Baseline performance was established in the runs made without BCAS. There were 198 transponder-equipped aircraft in the early 1980 postulated environment, 154 of which were assumed to be BCAS-equipped with DABS transponders, with the remaining 44 aircraft assumed to be equipped with ATCRBS transponders with both mode A (identity) and mode C (altitude) capability. Two ground environments were modeled. One, consisting entirely of ATCRBS interrogators, was selected from ECAC's IFF files. The other, consisting of 25% DABS sensors and 75% ATCRBS interrogators, was created by changing FAA site interrogators to DABS sensors. ATCRBS ground system performance was evaluated in terms of the predicted ability of the ground system to detect targets, and validate mode A and mode C codes. The model was also used to perform a parametric analysis of the power programming feature of the BCAS, and to predict fruit rates at an airborne BCAS interrogator.

## SECTION 2

## SYSTEM DESCRIPTION

ATCRBS/DABS AIR TRAFFIC SURVEILLANCE SYSTEMSATCRBS

The ATCRBS<sup>2</sup> consists of airborne transponders, ground-stationed interrogator, antenna system, and processing equipment. ATCRBS interrogations are transmitted at the rate of several hundred per second using a narrow beam (1°-4°) antenna which rotates to cover a full 360° of azimuth several times per minute.

All aircraft equipped with ATCRBS transponders and that are within line-of-sight and located in the antenna mainbeam can reply. Interrogators may elicit 20 or more replies from each aircraft within the mainbeam.

The principal information determined from the replies consists of aircraft range, azimuth, identification, and altitude. The system processor automatically displays this information for use by the air traffic controller.

The increase in air traffic and number of ground interrogators has in turn increased demands on this system, thus taxing its viability, and has led to the development of DABS as a replacement of ATCRBS. A complete description of ATCRBS can be found in Reference 2.

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<sup>2</sup>"U.S. National Standard for the IFF MARK X (SIF)/Air Traffic Control Radar Beacon System Characteristics," Agency Order 1010.51A FAA, Washington, D.C., March 1971.

DABS

DABS<sup>3</sup> is being designed to be compatible with the existing ATCRBS, because the transition will be gradual and the air traffic control (ATC) function must be maintained while both ATCRBS and DABS transponders and interrogators are in use.

In addition to the ATC function, the DABS system has the capability of providing intermittent positive control (IPC), an automatic ground-based conflict detection and resolution service.

The principal difference between ATCRBS and DABS is the use of discretely addressed interrogations by DABS. Since each aircraft has a unique address, it will reply only to its unique address once a track has been initiated. By tracking each aircraft and using the unique address capability, DABS is able to schedule interrogations both to minimize uplink transmission rates and prevent synchronous garble. A complete description of DABS is contained in Reference 3.

BCAS - GENERAL

The active BCAS (FIGURE 1) analyzed in this report is intended to provide the collision avoidance function during the evolution of DABS IPC and in areas outside ground IPC coverage thereafter. It is designed to detect and track ATCRBS- or DABS-transponder-equipped aircraft that present a possible collision threat to the BCAS-equipped aircraft. Active BCAS uses airborne DABS and ATCRBS interrogators operating at low interrogation rates to obtain altitude, range and range rate data of aircraft in the surrounding environment.

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<sup>3</sup>Drouilhet, P. R., *DABS: A System Description*, FAA-RD-74-189, Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA, 18 November 1974.

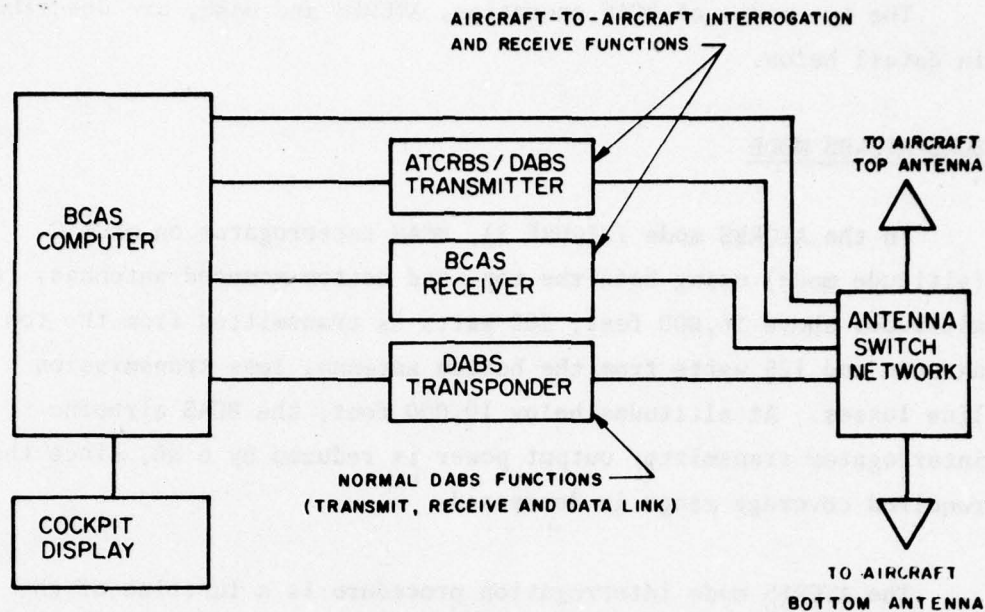


FIGURE 1. ACTIVE BCAS.

The BCAS computer establishes and updates a track of encountered aircraft in altitude and range, determines potential collisions and then displays to the pilot the appropriate avoidance-maneuver procedure.

The BCAS system also requires deployment of a ground-based DABS desensitization control unit transponder at each airport where aircraft separations resulting from normal ATC procedures would result in unacceptably high false alarm rates. These DABS transponders would be interrogated by BCAS-equipped aircraft and the resulting replies recognized as coming from a desensitization control unit (DCU). BCAS will then compute its own range and altitude to the DCU and terminate its own CAS function within range and altitude limits specified in the desensitization unit ground-to-air link.

The two modes of BCAS operation, ATCRBS and DABS, are described in detail below.

#### BCAS/ATCRBS MODE

In the ATCRBS mode (FIGURE 2), BCAS interrogates on mode C (altitude mode) using both the top- and bottom-mounted antennas. At altitudes above 10,000 feet, 500 watts is transmitted from the top antenna and 125 watts from the bottom antenna, less transmission line losses. At altitudes below 10,000 feet, the BCAS airborne interrogator transmitter output power is reduced by 6 dB, since the required coverage range is decreased.

The ATCRBS mode interrogation procedure is a function of the garble (overlapping reply level) at the BCAS receiver. A low-density interrogation procedure is employed when the number of detected overlapping replies is less than four. A high-density interrogation procedure is employed when the number of detected overlapping replies is four or more.

#### Low-Density Procedure

When less than four overlapping replies are received, a full-power mode C interrogation is transmitted from the top antenna. Approximately 350  $\mu$ s later, after receiving replies, a P1-P2 suppression pulse pair is transmitted from the top antenna at the same power as the interrogation. Those transponders that received the interrogation from the top antenna will be suppressed by this procedure. While they are still suppressed (approximately 20  $\mu$ s after transmission of the P1-P2 suppression), a mode C interrogation is transmitted from the bottom antenna. This procedure is repeated once per second.

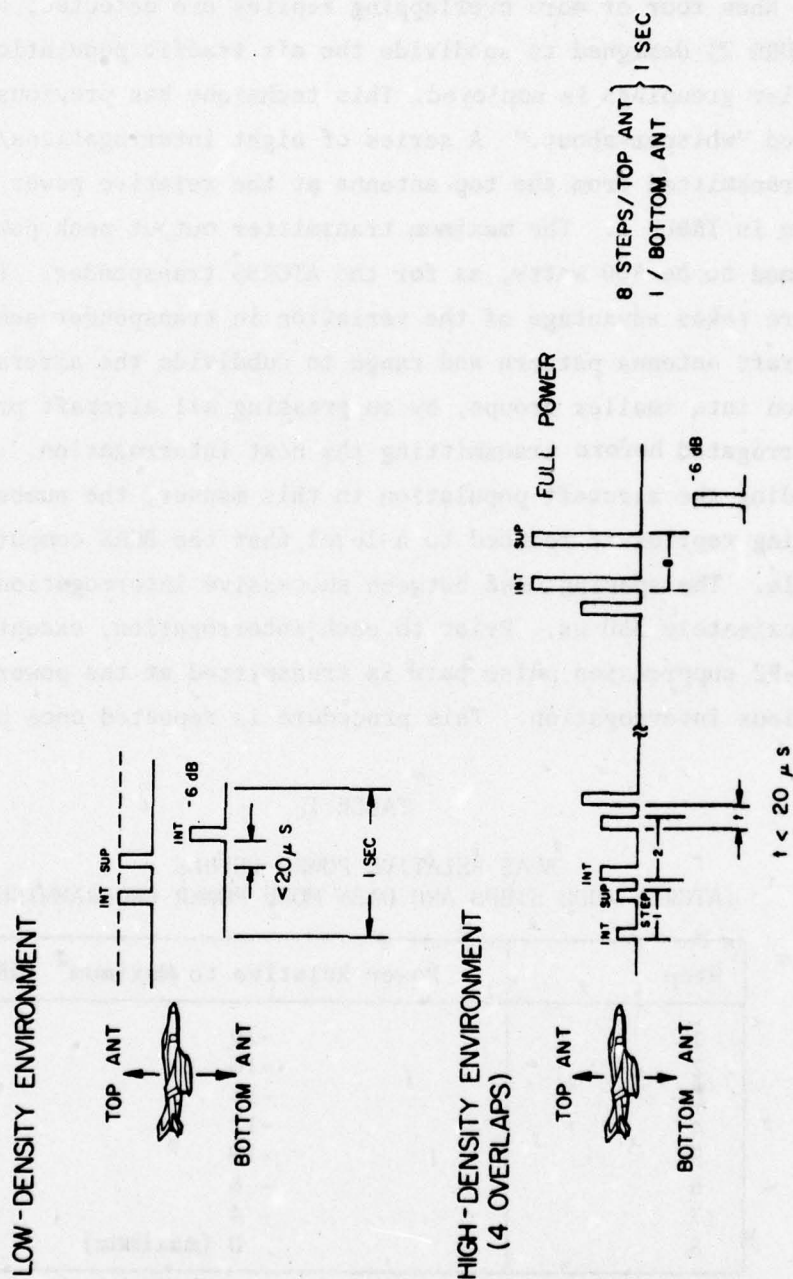


FIGURE 2. BCAS/ATCRBS MODE.

High Density Procedure (Whisper-Shout)

When four or more overlapping replies are detected, a procedure (FIGURE 2) designed to subdivide the air traffic population into smaller groupings is employed. This technique has previously been called "whisper-shout." A series of eight interrogations/suppressions is transmitted from the top antenna at the relative power levels shown in TABLE 1. The maximum transmitter output peak power is assumed to be 500 watts, as for the ATRBS transponder. This procedure takes advantage of the variation in transponder sensitivity, aircraft antenna pattern and range to subdivide the aircraft population into smaller groups, by suppressing all aircraft previously interrogated before transmitting the next interrogation. By subdividing the aircraft population in this manner, the number of overlapping replies is reduced to a level that the BCAS computer can handle. The spacing used between successive interrogations is approximately 350  $\mu$ s. Prior to each interrogation, except the first, a P1-P2 suppression pulse pair is transmitted at the power of the previous interrogation. This procedure is repeated once per second.

TABLE 1

BCAS RELATIVE POWER LEVELS  
(ATRBS MODE STEPS AND DABS MODE POWER PROGRAMMING)

Step	Power Relative to Maximum <sup>a</sup> (dB)
1	-19
2	-16
3	-14
4	-12
5	-10
6	- 8
7	- 4
8	0 (maximum)

<sup>a</sup>500 watts

ATCRBS Mode Jitter

To prevent synchronous interference while interrogating in the ATCRBS mode, BCAS spaces ATCRBS interrogation trials at  $1 + k$  second intervals, where  $k$  is randomly assigned a value between  $+0.1$  and  $-0.1$ . This procedure is referred to as jitter.

BCAS/DABS MODE

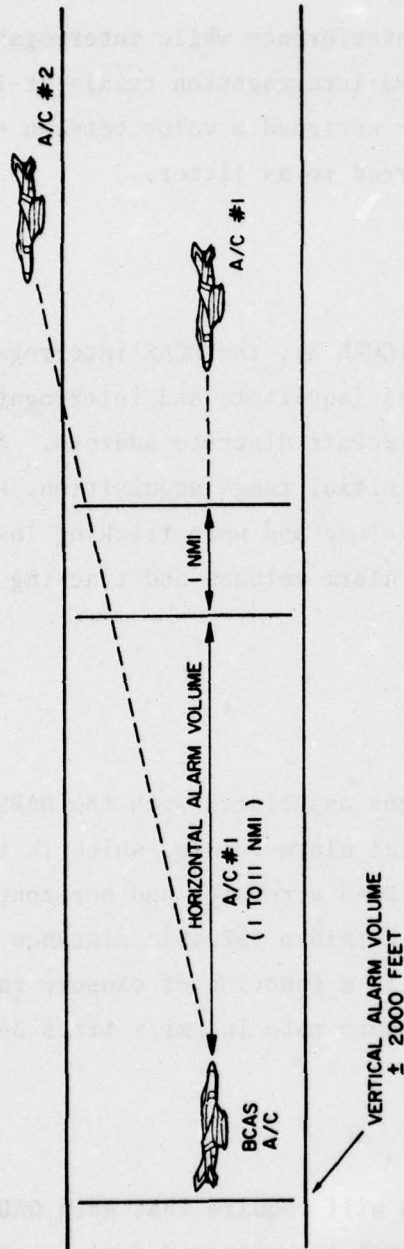
In the BCAS/DABS mode (FIGURE 3), the BCAS interrogator listens for DABS aircraft transmissions (squitter) and interrogates individual aircraft using the DABS aircraft discrete address. Active interrogations are made during initial range acquisition, when tracking outside the horizontal alarm volume and when tracking inside the horizontal alarm volume. The alarm volumes and tracking procedures are described below.

Alarm Volume

There are two alarm volumes associated with the DABS mode as shown in FIGURE 3: the vertical alarm volume, which is the airspace 2000 feet above and below the BCAS aircraft; and horizontal alarm volume, which is the airspace within a variable distance of 1 to 11 nmi. Horizontal alarm volume is a function of closure rate and is computed as 1 nmi plus the closure rate in nmi/s times 30 seconds.

Squitter Acquisition

Deployment of active BCAS will require that each DABS transponder-equipped aircraft transmit a squittered reply containing altitude and address information at a rate of approximately once per second. BCAS receivers listen to these squittered transmissions and



BCAS Tracks DABS A/C as follows:

1. Listens to squitter to track vertical separation.
2. Initial range acquisition (ACTIVE) 4 seconds prior to entering vertical alarm volume.
3. Active interrogation outside horizontal alarm volume.
4. Active power programming inside horizontal alarm volume.

FIGURE 3. BCAS/DABS MODE.

compute altitude separation and altitude closure rate between their own aircraft and the DABS-equipped intruder. When these computations indicate that the intruder will penetrate the vertical alarm volume, BCAS directs addressed interrogations to the intruder aircraft. If the intruder aircraft is above the BCAS aircraft, the top antenna is used for these interrogations; if it is below, the bottom antenna is used.

#### Initial Range Acquisition

The initial range interrogation procedure consists of a maximum of eight interrogations (at a maximum power of 500 watts) to obtain range and range rate of the intruding aircraft. The actual number of interrogations (2-8) used is a function of reply overlaps and missing replies and will be discussed later. The BCAS computer uses range and range rate information to determine if the intruding aircraft has entered or will enter the horizontal alarm volume. If there are no replies to the initial range acquisition attempt, the procedure will be repeated at 10-second intervals as long as the aircraft remains in the vertical alarm volume.

#### Tracking Outside Horizontal Alarm Volume

While an intruder aircraft remains outside the horizontal alarm volume, but within the vertical alarm volume, it will be tracked by discretely addressed active BCAS interrogations. The time at which the intruder aircraft could reach the horizontal alarm volume plus 1 nautical mile is estimated based on the assumption of a maximum closure rate of 1000 knots. Active interrogations are sent out at this time to update the track. The maximum time allowed between updates is 10 seconds and the minimum, 1 second. A maximum of eight interrogations per update interval are transmitted until two successful interrogations are completed.

Tracking Inside Horizontal Alarm Volume

When an aircraft enters the horizontal alarm volume, a power programming scheme is employed which attempts to interrogate at reduced power as the aircraft range is reduced. Eight power levels (the same relative levels as shown in TABLE 1 for the ATCRBS mode) are used. During the first 5 seconds of tracking in the horizontal alarm volume, DABS interrogations are transmitted at full power (500 watts). If not more than three successive interrogation failures occur during this time, the power level is reduced one step and held at the new power setting for 5 seconds. This process continues until the minimum usable power is reached. If three successive failures occur, the power is raised a step.

DABS BCAS Mode Interrogation Rates

The rate at which BCAS interrogates DABS aircraft is a function of the number of missing and overlapped replies.

While tracking an aircraft within the horizontal alarm volume plus 1 nautical mile, BCAS continuously interrogates at a rate that varies from one to four interrogations per second. If replies are garbled (four or more overlapping replies), the rate is four interrogations per second. If there are missed replies, the interrogation rate is two per second. If replies are successfully received (neither missed nor garbled) the rate is one interrogation per second.

While tracking outside the horizontal alarm volume plus 1 nautical mile, interrogations occur until two successful replies are returned or a maximum of eight interrogations are transmitted.

## SECTION 3

## MODEL DESCRIPTION

GENERAL

The computerized model used to simulate active BCAS operation in the DABS/ATCRBS environment consists of a BCAS submodel merged with ECAC's DABS/ATCRBS PPM (Performance Prediction Model). The model is written in FORTRAN V and is run on ECAC's Univac 1110 Computer.

The DABS/ATCRBS PPM consists of a number of subroutines that simulate the operation of a DABS or ATCRBS victim interrogator in an environment consisting of both DABS and ATCRBS sensors and transponders. The performance of an interrogator of interest is predicted in terms of transponder reply histories, fruit rate, and automated processor target detection and code validation.

The active BCAS routine models the operation of all the airborne BCAS interrogators in the environment. It generates DABS BCAS interrogation and ATCRBS BCAS interrogation and suppression arrival times at each airborne transponder. These BCAS signals are then merged with the signal environment created by the ground system interrogators at the input to the transponder model in the DABS/ATCRBS PPM.

The model is run with and without the BCAS submodel to evaluate the impact of BCAS on ground system performance. A more detailed description of the BCAS routine and the DABS/ATCRBS PPM follows.

DABS/ATCRBS Performance Prediction Model

The DABS/ATCRBS/IFF MARK XII System PPM or DABS/ATCRBS PPM provided the foundation for the BCAS modeling and analysis effort. The DABS PPM was originally developed as part of the DABS Spectrum Management Program to provide a prediction capability that simulates the proposed coexistence of the DABS and ATCRBS air traffic control systems.

The DABS/ATCRBS PPM is a time-event-store model of the system functions of the DABS and ATCRBS. The standard model inputs consist of the three basic categories listed in TABLES 2 and 3.

TABLE 2

DABS/ATCRBS PPM INPUTS

Sensor/Interrogator Environment	Transponder Environment
Latitude	Latitude
Longitude	Longitude
Site Elevation/Antenna Height	Altitude
Output Power	Output Power
Receiver Sensitivity	Receiver Sensitivity
Sidelobe Suppression Type	Mode Capability
Pulse Repetition Frequency	Antenna Type
Mode Interlace	
Antenna	
Mainbeam Gain/Width	
Sidelobe Gain/Width	
Backlobe Gain/Width	
Scan Rate	

TABLE 3

DABS/ATCRBS PPM  $I_0$  CHARACTERISTICS

Interrogator Environment Selection Radius
Range Factor
STC Characteristics
ATCRBS Processor Target Detection Parameters
Target Start
Begin Validation
Target End
Target Detection Threshold
Range Bin Size or Correlation
Simulation Time

*Input.* The simulation cycle for the DABS/ATCRBS PPM is one pulse repetition period (PRP) of the victim interrogator or interrogator-of-interest ( $I_0$ ). For DABS sensors, one PRP is defined as the time between transmissions of all-call interrogations. A flow diagram of the DABS/ATCRBS PPM is shown in FIGURE 4. Subroutine INPUT, shown in the figure, performs the basic functions of reading in all input data, performing the interrogator file radius cull, and ordering the environmental data into the appropriate arrays for efficient access by later routines.

*Channel Management.* The main loop of program execution begins in subroutine ACTIVE. In ACTIVE, all DABS sensors search their active target list to determine which targets, based on last reported range and azimuth, are expected to be in the mainbeam during the present simulation cycle. The active target list is maintained in subroutine ACTIVE by means of a target list update which is accomplished for all DABS sensors in the simulated environment. The target list update is based on the results of past all-call and roll-call transactions attempted with DABS-equipped aircraft.

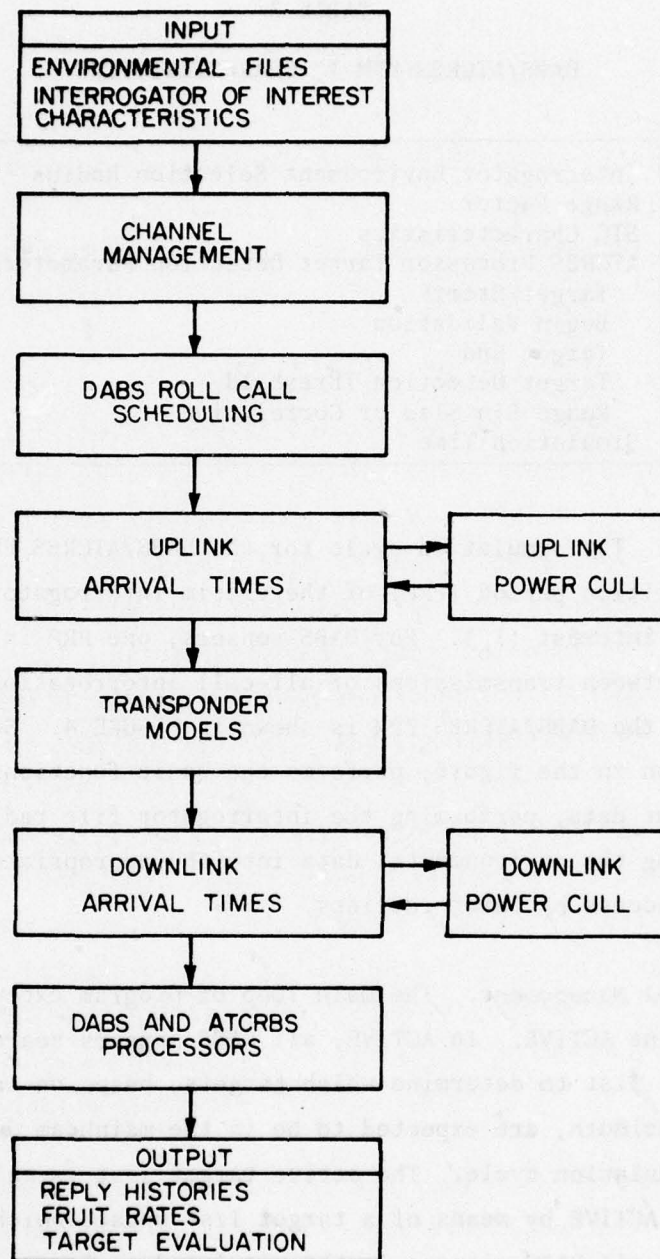


FIGURE 4. DABS/ATCRBS PPM FLOW DIAGRAM.

*DABS Scheduling.* After completing the channel management portion of the program in subroutine ACTIVE, program control is passed to subroutine ROLCAL. ROLCAL establishes the all-call and roll-call interrogation times for the present simulation cycle. Roll-call transactions are scheduled to the appropriate targets in decreasing range order and are spaced so as to avoid synchronous garble and overlapping of the transmit and receive functions.

*Uplink Power Cull.* The arrival times of all types of interfering interrogations and suppressions for each DABS- or ATCRBS-equipped aircraft in the  $I_0$ 's mainbeam are established in subroutines DABINT and P1-P2. First, the coupling between the interferer and  $I_0$  antennas is determined based on their respective rotation rates and the elapsed time from the last simulation cycle. Subroutine PLOSS is accessed to calculate the received signal strength at the transponder based on free-space path loss, sensor output power, line loss, and sensor and aircraft antenna gains. If the signal level is greater than the transponder sensitivity, the interrogation or sidelobe suppression time is stored in the appropriate array.

*Transponder Models.* Subroutine OVRLAP simulates the operation of the transponder. For either a DABS- or ATCRBS-equipped aircraft, the arrival time of the  $I_0$  interrogation is compared with the arrival times of each type of interfering signal (other interrogation or SLS). OVRLAP then determines whether the  $I_0$  interrogation signal is decoded depending on the dead time attendant to each interfering signal. Other interference devices, such as false sidelobe suppressions and intermode garble, are also checked by the transponder model. The model then outputs the reply times generated by the signal environment for all replies which pass the downlink power cull. These times are based on the transmission time of the interrogation, the propagation time and the processing time at the transponder.

*Downlink Power Cull.* The calculation of nonsynchronous reply arrival times is accomplished in subroutines FRUIT and SLFRT, with FRUIT determining  $I_0$  mainbeam arrival times and signal strengths and SLFRT performing the same operations for the  $I_0$  sidelobes. The model operation in these subroutines calculates the arrival time and signal strength of fruit replies to the  $I_0$ . Those replies which pass the downlink power cull are retained for the processor routines.

*DABS Processor.* Several target evaluators are built into the model to accommodate variations in the types of FAA processors. The basic routine is subroutine PROCES, which simulates the processing of DABS all-call and roll-call replies. PROCES receives as input the arrival times of each type of reply, synchronous and nonsynchronous, entering the processor. The arrival times are checked for overlaps, and a determination is made as to whether the valid replies are decoded correctly based on the location and length of the error, the type of overlapping reply, and the relative signal strengths.

*ATCRBS Processor.* The simulation of the ATCRBS processor, subroutine ATEVAL, maintains hit and miss counts for each in-process target, and correlates replies whose time-of-arrival places them in the range bin appropriate to the type of processor used with the  $I_0$ . The times-of-arrival are also used to determine reply overlaps. Garble flags are maintained for each target in the course of simulating code validation processes.

*Output.* The model outputs are summarized in TABLE 4. The outputs from the DABS and ATCRBS target processors are fed back to the beginning of the simulation cycle, subroutine ACTIVE. Another cycle is then initiated based on the completion of roll-call transactions, the acquisition of new targets by all-call, and the transition of old targets out of and new targets into the mainbeam of the  $I_0$ .

TABLE 4

## DABS/ATCRBS PPM OUTPUTS

Transponder PerformanceProbability of reply to the  $I_o$  for each aircraft

Target run lengths

Reply histories

Reply arrival times

Location of missed replies in run length

Cause of missed replies

Identity of interferer

Interrogator-of-Interest Performance

Fruit rate after each simulation cycle

ATCRBS

All call

Roll call

Fruit reply times and garbles

Valid reply times

ATCRBS target detection summaries

Target declaration

Code validation indicator

Azimuth and range

Target start and end azimuths

DABS transactions

Reply times

Garble conditions

Azimuth and range

BCAS SIMULATION ROUTINE

The BCAS routine provides the DABS/ATCRBS PPM with arrival times of BCAS signals at each transponder in the modeled environment by creating arrays that store the arrival times of four types of signals

that may arrive at each transponder from all deployed BCAS. The four signal types are:

1. ATCRBS interrogations
2. ATCRBS suppressions
3. DABS interrogations with the address of the DABS target transponder
4. DABS interrogations with an address other than that of the DABS target transponder.

#### Simulation of BCAS/ATCRBS

The BCAS routine generates all BCAS ATCRBS mode interrogation and suppression times. To determine the BCAS interrogation schedule in the ATCRBS mode, it is necessary to first determine if the BCAS is operating in a low-density environment (transmitting one interrogation and one suppression per second) or a high-density environment (transmitting the 8-step power programming procedure).

The state of each BCAS (less than four overlapping replies for low-density operation and four or more for high-density operation) is determined by combining the number of synchronous overlapping desired replies with the asynchronous arrival of fruit overlaps. The number of synchronous overlaps is determined by finding the maximum number of ATCRBS aircraft contained in any 1.65-nmi range increment about the BCAS aircraft. These aircraft will return replies that overlap a 20.3- $\mu$ s reply train length. The number of asynchronous replies is found by assuming a Poisson arrival distribution of airborne fruit obtained through interaction with the DABS/ATCRBS PPM.

Once the BCAS routine determines which BCAS interrogators are in power programming, a power cull between each BCAS interrogator and ATCRBS-equipped aircraft is made to determine the rate at which

signals arrive above the ATCRBS transponder sensitivity. The BCAS routine assumes the ATCRBS-transponder-equipped aircraft receive on bottom-mounted antennas. The random jitter feature of the BCAS/ATCRBS interrogation mode is simulated by pseudorandomly generating the time of the first interrogation in an ATCRBS trial. During the low-density operation a P1-P2 suppression pulse pair follows this interrogation by 330  $\mu$ s. The P1-P2 interrogation pulse pair from the bottom antenna is scheduled 20  $\mu$ s after the suppression. During high-density operation, the additional six interrogations from the top antenna and the one from the bottom antenna are scheduled at 350- $\mu$ s intervals. Each is preceded by a P1-P2 suppression pulse pair 20  $\mu$ s prior to the interrogation.

#### Simulation of BCAS/DABS

To simulate the DABS signal environment, all DABS outputs of one BCAS are found. These outputs are then passed against all aircraft transponders in the modeled environment. Two arrays, one with arrival rates of DABS interrogations having the DABS target address and one with DABS interrogations having addresses other than that of the target aircraft, are maintained. The BCAS routine cycles through all BCAS-equipped aircraft and updates the arrival rate arrays by adding the effects of each BCAS as its outputs are created.

The BCAS routine uses the following step-by-step procedure to generate the signal environment at any one DABS aircraft:

1. Check identification to insure target aircraft is DABS-transponder-equipped.
2. Eliminate from consideration any DABS aircraft that remain outside the BCAS vertical alarm distance ( $\pm 2000$  feet) during the simulation.

3. Compute the power levels of the squittered DABS replies received by the subject BCAS from the target aircraft and eliminate the aircraft from consideration if the reply is received below the BCAS receiver sensitivity.

4. Compute the power levels of the BCAS interrogations received by the DABS aircraft and the power levels of the DABS aircraft replies received by BCAS. If no communication is established, the BCAS interrogation rate will be 8 interrogations every 10 seconds for an effective rate of 0.8 interrogations per second. (Initial range acquisition is repeated at 10-second intervals.)

5. Compute range and range rate if communication link is established in step 4. Compute horizontal alarm volume as the distance required for separation to be reduced to 1 nmi in 30 seconds at the current range rate. If range is within the horizontal alarm volume, BCAS transmissions are scheduled in step 6; if outside this volume, in step 7.

6. Compute the signal environment for BCAS to DABS aircraft inside the horizontal alarm volume. The model computes the expected interrogation rate for continuous tracking and assumes the minimum power programming level capable of establishing communication with each DABS aircraft with respect to each BCAS aircraft. The Engineering Requirement (Reference 1) of the proposed BCAS system states that the rate of interrogation will be one per second while replies are successfully elicited; two per second when any replies are missed; and four per second when any replies are garbled. Test data<sup>4</sup> supplied to ECAC shows the probability of successfully decoding a DABS reply,  $P(dc)$ , as a function of fruit rate and received power level. This information is used in the model to compute the probability of garble,  $P(g) = 1 - P(dc)$ . The probability of a target miss  $P(m)$  is obtained from the target reply history through interaction

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<sup>4</sup>McDonald, T. S., *BCAS DABS Reply Processing Performance Analysis*, Report No. 42W-5062, Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA, 8 October 1976.

with the DABS/ATCRBS PPM. When replies are neither garbled nor missed, a successful target hit is assumed with the probability of a hit,  $P(h) = 1 - P(g) - P(m) + P(m) P(g)$ . Thus, the expected interrogation rate for any BCAS-DABS couplet  $E(INTRT)$  is computed as  $E(INTRT) = 1 \times P(h) + 2 \times P(m) + 4 \times P(g)$ . The upper bound is four interrogations per second.

7. Compute the signal environment for BCAS to DABS aircraft outside the horizontal alarm volume. Outputs occur at variable time intervals such that the track may be updated at the time predicted for the DABS aircraft to be within 1 nmi of the horizontal alarm volume assuming a closure rate of 1000 knots. The model uses the probabilities discussed in step 6 to obtain the expected number of interrogations required to obtain two successful replies (hits). The maximum per interval is limited to eight. Thus, from two to eight interrogations will be scheduled per update interval. The maximum update interval is assumed to be 10 seconds and the minimum, 1 second. The maximum allowable interrogation rate is four per second.

The aperiodic scheduling of the active BCAS DABS mode interrogations is simulated by a uniform distribution of transmission times. The distribution of transmission times is based on the expected interrogation rate generated in steps 6 and 7 above. A flow diagram of the BCAS simulation routine is shown in FIGURE 5.

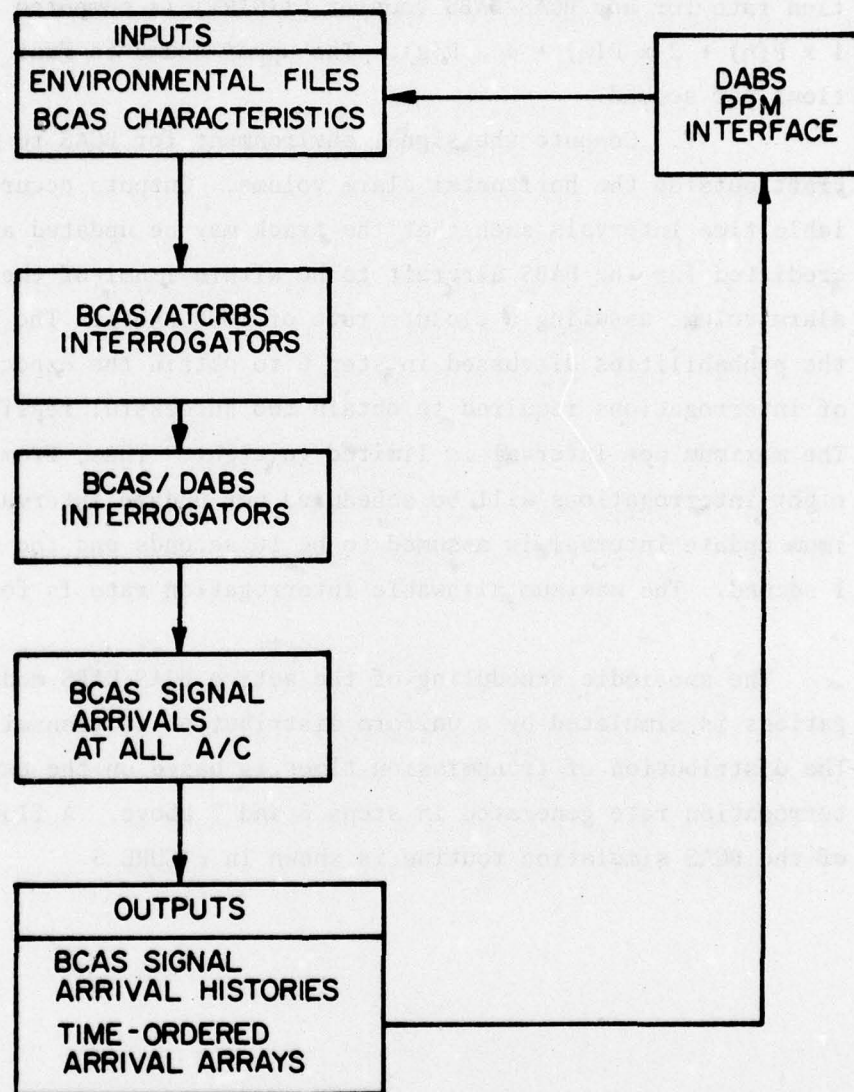


FIGURE 5. BCAS FLOW DIAGRAM.

## SECTION 4

## ANALYSIS

ATCRBS INTERROGATOR PERFORMANCE

To determine the impact on ATCRBS performance at the Washington, D. C., terminal of deploying active BCAS in the airborne environment, the ATCRBS ground performance with and without active BCAS was predicted. The performance of an ATCRBS ground interrogator is based on the ability of the ground system to detect targets, and to validate mode A (identity) and mode C (altitude).

Because active BCAS transmits ATCRBS interrogations and suppressions and DABS interrogations, the total dead time of transponders within its range is increased, thereby potentially degrading the ability of the ground system to detect targets. The additional replies elicited by the active BCAS interrogations appear as fruit to the ground system, potentially degrading the DCA ARTS III processor's ability to validate mode A and mode C.

The following dead times were assumed for this analysis:

<u>BCAS Transmission</u>	<u>Transponder Type</u>	<u>~ Transponder Dead Time (μs)</u>
ATCRBS Interrogation	ATCRBS	60
ATCRBS Suppression	"	35
DABS Interrogation	"	35
ATCRBS Interrogation	DABS	35
ATCRBS Suppression	"	35
DABS Interrogation (at transponder address)	"	200
DABS Interrogation (not at transponder address)	"	35

### Aircraft Deployment

The aircraft deployment used for the analysis was based on predicted 1981 air traffic densities for the Washington, D.C., National Airport (DCA) area. To obtain the hypothetical deployment, a 1975 target listing from the Suitland enroute site was augmented with an assumed growth rate of 3% per year. The resulting deployment contained a total of 198 transponder-equipped aircraft within a radius of 200 nmi<sup>a</sup> around DCA. Of the total, 154 were assumed to have BCAS equipment including a DABS transponder. The remaining 44 aircraft were assumed to have ATCRBS transponders with mode C and mode A capability.

The deployment is shown in FIGURE 6 and the distribution of aircraft in range and altitude is shown in TABLE 5.

### Ground-Based DABS DCU Transponders

In addition to the airborne transponder deployment described above, approximately 25% of all airports (all FAA sites including DCA) were assumed to have DABS transponders serving as DCU's located on the ground approximately 1 nmi from the ATC interrogator.

### Ground Interrogator of Interest

The analysis was conducted to predict the impact of active BCAS on the performance of the ATCRBS interrogator located at DCA. The interrogator is associated with an ARTS III processor. TABLE 6 is a list of the characteristics of this interrogator.

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<sup>a</sup>The 200 nmi radius was chosen since aircraft within this radius can contribute fruit to the DCA ground receiver.

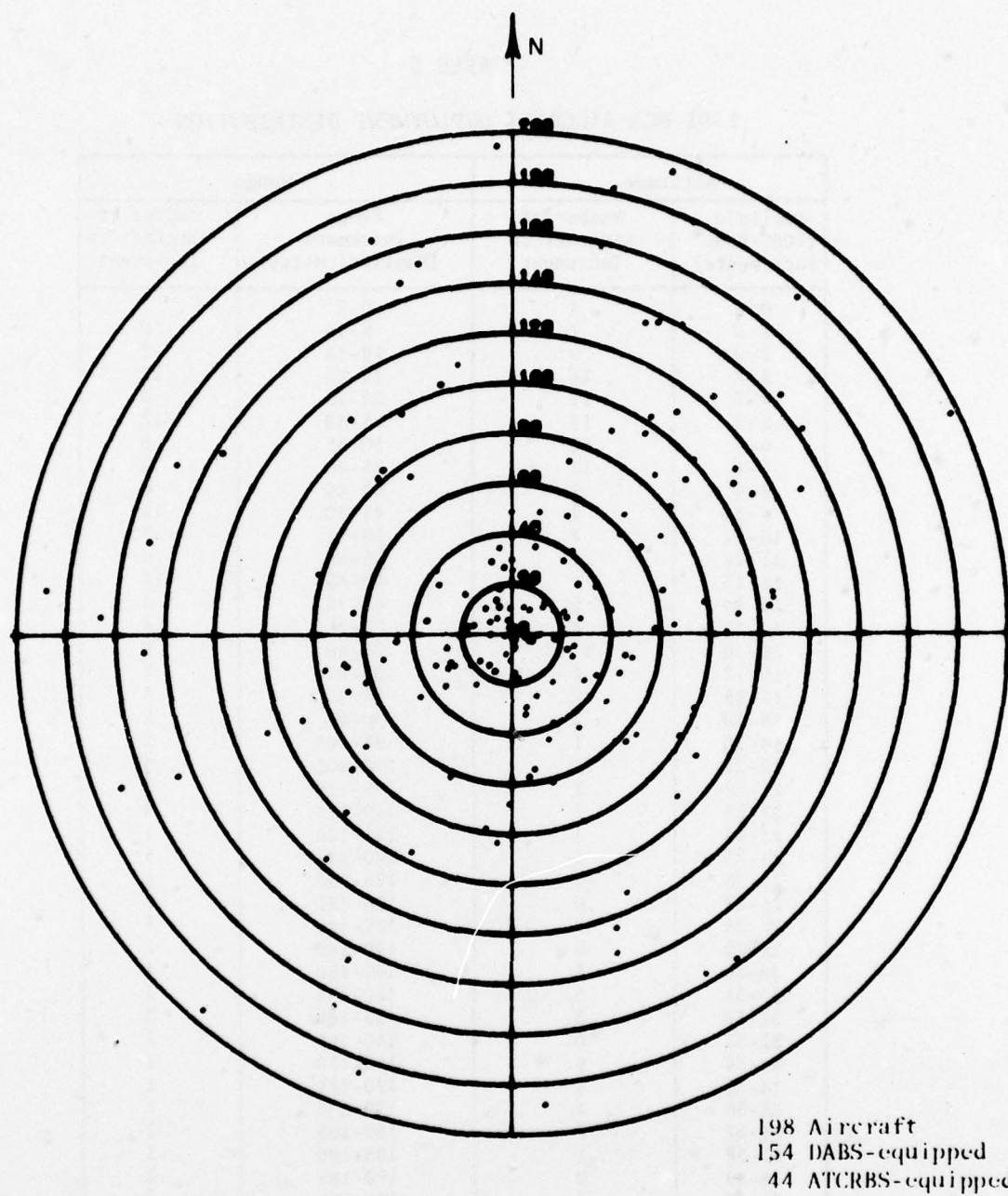


FIGURE 6. DCA 1981 AIRCRAFT DEPLOYMENT.

TABLE 5

## 1981 DCA AIRCRAFT DEPLOYMENT DISTRIBUTION

Altitude		Range	
Altitude (1000-foot Increments)	Number of Aircraft in Increment	Range Increment (Nautical Miles)	Number of Aircraft in Increment
0-1	4	0-5	7
1-2	7	5-10	9
2-3	9	10-15	7
3-4	16	15-20	17
4-5	11	20-25	8
5-6	18	25-30	12
6-7	12	30-35	8
7-8	12	35-40	8
8-9	5	40-45	6
9-10	8	45-50	11
10-11	7	50-55	3
11-12	1	55-60	4
12-13	4	60-65	10
13-14	0	65-70	4
14-15	4	70-75	4
15-16	11	75-80	9
16-17	2	80-85	8
17-18	2	85-90	3
18-19	2	90-95	5
19-20	1	95-100	5
20-21	6	100-105	4
21-22	2	105-110	7
22-23	2	110-115	3
23-24	3	115-120	1
24-25	5	120-125	3
25-26	7	125-130	1
26-27	0	130-135	2
27-28	2	135-140	3
28-29	3	140-145	2
29-30	3	145-150	4
30-31	5	150-155	3
31-32	2	155-160	3
32-33	0	160-165	1
33-34	9	165-170	2
34-35	0	170-175	1
35-36	4	175-180	1
36-37	2	180-185	2
37-38	1	185-190	3
38-39	0	190-195	2
39-40	3	195-200	2
40-41	0		
41-42	2		
42-43	0		
43-44	1		

TABLE 6

## LOCATION AND CHARACTERISTICS OF DCA VICTIM INTERROGATOR

Latitude	38° 51' 42" N
Longitude	77° 02' 02" W
Total Height	40 feet
Peak Power	0.1 kW
Receiver Sensitivity	-87 dBm
Scan Rate	13 RPM
PRF	Staggered
SLS Type	Improved SLS
Range of Receiver	200 nmi
Mode Sequence	3/A, 3/A, C
Mainbeam Gain	+21 dBi
Sidelobe Gain	- 7 dBi
Backlobe Gain	-19 dBi
Mainbeam Width	4°
Sidelobe Width	56°
Backlobe Width	300°
Interrogator	ATCBI-0004
Primary Radar Nomenclature	ASR-0007
Directional Antenna	Hazeltine-Tapered
STC Curve (Initial Depth)	40 dB

Ground Interrogator Environment

The ground interrogator environment consisted of all 219 interrogators (including special-purpose) within a 500-nmi<sup>a</sup> radius of Washington, D.C.

<sup>a</sup>The 500-nmi radius was selected since aircraft within range of the DCA ground receiver may reply to some of these interrogators.

Predictions were made with all the interrogators operating in a present-day ATCRBS configuration, and then with a mix of 25% DABS sensors/75% ATCRBS interrogators. Only FAA-controlled interrogators were selected to be DABS sensors.

#### PERFORMANCE PREDICTIONS

Four simulation runs were made. The all-ATCRBS ground environment and the 25%/75% DABS/ATCRBS ground environment were run both with and without BCAS.

#### Reply Performance

TABLE 7 shows these predictions as referenced to the DCA central interrogator. The average transponder probability of reply to ATCRBS given in the table is found by dividing the total number of transponder replies to the DCA interrogations for a complete 360° scan of the DCA mainbeam by the total number of interrogations in the same scan. Deploying BCAS caused four replies to be lost over one scan in both ground environments. There are 198 aircraft within range of DCA that receive approximately 18 valid interrogations per scan summing to approximately 18 x 198 (3564) valid interrogations per scan. The four replies lost due to BCAS, therefore, degrade the average probability of reply by approximately one part per thousand, as can be seen in the table.

TABLE 7 also shows the range of individual probabilities. Deploying BCAS did not significantly affect the range or distribution of individual reply probabilities. The approximate distribution of lost replies for all runs remained as follows:

65% lost no replies	10% lost two replies
15% lost one reply	10% lost three to six replies

TABLE 7

## SIMULATION RESULTS AT THE DCA INTERROGATOR

Performance Criteria	All-ATCRBS Ground Environment		25%/75% DABS/ATCRBS Ground Environment	
	Without BCAS	With BCAS	Without BCAS	With BCAS
Average Transponder Prob. of Reply	0.957	0.956	0.963	0.962
Individual Transponder Prob. of Reply Range	0.66-1.0	0.66-1.0	0.66-1.0	0.66-1.0
Maximum Reduction <sup>a</sup> in Individual Transponder Reply Prob. due to BCAS	-	5.6%	-	5.6%
ATCRBS Fruit Rate	1211/s	1245/s	801/s	843/s
Roll Call Fruit Rate	0	22/s	31/s	54/s
Replies Blanked due to Roll Call Fruit <sup>b</sup>	-	12	17	29
All-Call Fruit Rate	0	0	128/s	130/s
Mode A Validation Probability	1.0	1.0	1.0	1.0
Mode C Validation Probability	0.99	0.99	0.99	0.99

<sup>a</sup> Four aircraft lost one reply each.

<sup>b</sup> Loss of replies not sufficient to cause loss of code validation.

There are approximately 18 interrogations per mainbeam scan, so each lost reply represents a degradation in individual reply probability of 5.6% on any one scan. The four replies lost due to deploying BCAS occurred at four different aircraft such that the maximum reduction in individual reply probability was 5.6%.

#### Fruit Rates

The three types of fruit arriving at the DCA interrogator receiver are defined as follows:

ATCRBS fruit - ATCRBS replies elicited by ATCRBS and DABS interrogators other than the DCA interrogator.

ROLL CALL fruit - DABS transponder replies to addressed interrogations.

ALL CALL fruit - DABS replies elicited by DABS all call interrogations.

The ATCRBS fruit rate increased slightly, as shown in TABLE 7 when BCAS was deployed. The reduction in ground interrogation rate accompanying the 25%/75% DABS/ATCRBS ground system resulted in the expected reduction in fruit rate when compared to the all-ATCRBS ground environment.

The presence of DABS roll call fruit at the DCA interrogator caused the receiver to be blanked out to ATCRBS replies for the duration of a DABS reply. The DABS reply consists of an 8- $\mu$ s preamble followed by a data block of 56 or 112 bits, each of which is 1  $\mu$ s long. Assuming a long reply (120  $\mu$ s), the presence of DABS roll call fruit caused the ATCRBS interrogator receiver to be blanked to ATCRBS replies for a time equal to 120  $\mu$ s x (roll call fruit rate due to BCAS). TABLE 7 indicates that BCAS contributes 22 roll call fruit

per second and will therefore cause blanking 0.26% of the time. The rate of DABS roll call fruit due to the 25% DABS/75% ATCRBS ground system alone is 31/second or 0.37% blanking. The corresponding number of lost replies at the receiver is also shown in the table. Replies lost due to DABS roll call fruit did not affect target code validation for the simulation.

#### Target Detection and Code Validation

All targets were detected by the ARTS III processor for all performance runs made for this analysis. Mode A code was validated for all targets and performance runs. Two aircraft failed mode C code validation for all performance runs. These two aircraft appeared in the mainbeam at approximately the same azimuth and were separated in range by less than a reply length, resulting in a synchronous garble condition.

#### Individual Transponder Reply Probability

TABLE 8 summarizes the effect of deploying BCAS upon airborne transponders. The average increase in dead time was 1700  $\mu$ s which corresponds to a long-term average reduction in probability of reply of 0.17%. The maximum increase in dead time (8700  $\mu$ s) corresponds to a 0.87% reduction in reply probability.

Those aircraft that receive above-average BCAS-induced suppression and interrogation rates are located near the center of the aircraft deployment. Three aircraft experienced BCAS-generated dead time in excess of 6000  $\mu$ s; however, they did not lose replies due to BCAS. Their locations are (referenced to DCA):

<u>Bearing</u>	<u>Range</u>	<u>Altitude</u>
19.5 degrees	11.1 nmi	7200 feet
0.0 degrees	2 nmi	3000 feet
3.0 degrees	2 nmi	2500 feet

TABLE 8

## BCAS IMPACT ON TRANSPONDER PERFORMANCE

Average Increase in Dead Time	1700 $\mu$ s
Maximum Increase in Dead Time	8700 $\mu$ s
Average ATCRBS Interrogations Due to BCAS	7.6/s
Maximum ATCRBS Interrogations Due to BCAS	30.0/s
Average ATCRBS Suppression Due to BCAS	11.6/s
Maximum ATCRBS Suppression Due to BCAS	54.0/s
Average DABS Interrogation at "Others" Address	13.9/s
Maximum DABS Interrogation at "Others" Address	115.1/s
Average DABS Interrogation at "Own" Address	1.9/s
Maximum DABS Interrogation at "Own" Address	10.5/s

Fruit Rates at the BCAS

In addition to the runs described above, ECAC was tasked to make one run with an airborne BCAS interrogator as the victim to predict the level of airborne fruit. The one run was made with the aircraft 20,000 feet above Washington, D.C., and an all-ATCRBS ground interrogator environment assumed. The average fruit rate over one scan was 4000 per second. The maximum instantaneous fruit rate during any one pulse repetition period was 7200 fruit/second.

DABS Power Programming

ECAC was also tasked to determine the effects of DABS power programming schemes on the simulation results. A run was made assuming all BCAS would interrogate aircraft within their horizontal alarm volumes at full power. A 60- $\mu$ s increase per second in dead time resulted at one of the airborne transponders. DABS power programming had no detectable effect on ground system performance. The aircraft distribution in the Washington, D.C., area was such that only four of the BCAS aircraft had one DABS aircraft each in their horizontal alarm volumes. This resulted in only a small part of the total BCAS/DABS mode interrogations taking place under power programming. Consequently, using power programming did not reduce interference.

## SECTION 5

## SUMMARY OF RESULTS AND CONCLUSIONS

RESULTS

1. Active BCAS-induced interference resulted in a maximum predicted loss of one desired reply on any one Washington, D.C., (DCA) interrogator mainbeam illumination. A loss of one reply occurred for four separate targets. Reply loss was independent of changes in the ground environment.
2. The average predicted ATCRBS fruit rate at DCA increased approximately 3% with the inclusion of active BCAS interrogators in the environment. BCAS/DABS interrogations generated 22 roll-call fruit per second at the DCA terminal for the all-ATCRBS ground environment case. A 74% increase in roll-call fruit resulted for the mixed DABS/ATCRBS ground environment case when the BCAS was deployed. Twelve desired replies were blanked by the additional roll-call fruit over a period of one scan.
3. ARTS-III target detection and code validation predictions were unchanged in all cases with the inclusion of active BCAS.
4. Predicted ATCRBS fruit rates at an airborne BCAS (20,000 feet) averaged 4000/s with instantaneous rates reaching 7200/s.
5. DABS power programming did not affect the predicted performance of the ATCRBS in the DCA terminal environment.

CONCLUSIONS

1. Deploying active BCAS in the 1980's Washington, D.C., environment will result in a slight reduction in aircraft reply probability.
2. Deploying active BCAS in the 1981 Washington, D.C., environment will not impact the DCA ATCRBS ground receiver/processor performance.
3. DABS power programming is unnecessary in the Washington terminal environment used for this analysis.